A Climatology of Midlatitude Continental Clouds from the ARM SGP Central Facility:

Part II: Cloud fraction and radiative forcing

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**Goals:**
(1) What are the seasonal, monthly, and diurnal variations of total, and single-layer low, middle, and high cloud amounts at the ARM SGP site?
(2) What are the impacts of these clouds on the surface radiation budget?

**Time period:**
From January 1997 to December 2002
Data and Methods

Cloud radar/lidar to identify clear-sky, and cloudy periods.

Total clouds include all clouds

Single-layer clouds
- Low cloud (top ≤3km, no higher clouds above it)
- Middle cloud (3km ≤ cloud ≤ 6km; No higher clouds above and lower clouds below it)
- High cloud (base > 6km, no lower clouds below it)
The Best Estimate Flux Value Added Product (VAP) (Shi and Long 2002) for studying SW and LW fluxes and their CRFs.

\[ CRF_{SW} = \langle Q \rangle_{cldy} - \langle Q \rangle_{clear}; \]
\[ CRF_{LW} = \langle F \rangle_{cldy} - \langle F \rangle_{clear}; \]
\[ CRF_{NET} = CRF_{SW} + CRF_{LW} \]

where \( \langle Q \rangle_{cldy} \) and \( \langle F \rangle_{cldy} \) are net SW flux (down-up) and net LW flux during cloudy.

\( \langle Q \rangle_{clear} \) and \( \langle F \rangle_{clear} \) are net SW flux (down-up) net LW flux during clear sky.
For total and low clouds, more in winter than in summer. High clouds occur most and more in summer, middle clouds least.
Monthly variations of cloud fractions at the ARM SGP Site

For total/low clouds, maxima from December to March, minima in July-Aug. High clouds mirror the variation of low clouds with a local max. from May to Aug.
More clouds occurred during winter and spring, less during summer and fall, and big drops from June to July.

Conclusion: Total cloud fraction in this study represents a statistical value at SGP.
Annual/summer total and low clouds increase from midnight to local noon, then decrease to 1930 LT, during winter they have max. in mid-morning, min. in early evening. Annual/winter high clouds increase from 0300 to 1930 LT, then decrease
For all_sky/total/low clouds: their CRFs are similar with increased amplitudes, min. LW CRFs in summer, largest negative SW/NET CRFs in spring, smallest in winter. High_cloud CRFs mimic all_sky CRFs.
November-February is least NET CRFs for all clouds; April is greatest negative for all sky, total and low clouds; July for middle clouds, May-June for high clouds
LW CRFs depend on cloud-base height/temp, and emissivity. SW CRFs depend on solar insolation, optical depth and water vapor absorption. Low clouds have largest LW and SW CRFs, strong cooling effect on the surface. High clouds have least LW and SW CRFs, weak cooling effect on the surface. From NET CRFs, (1) total/low clouds - strong cooling; (2) others – weak cooling.
For SW flux, clear sky is greatest, low clouds have least due to optically thick, high clouds, all sky, middle clouds, and total clouds range from large to small. For LW flux, they are in the reverse order relative to SW flux.
Comparison of clear- and all-sky SW flux and CRF at the ARM SGP site

It is about 30 Wm\(^{-2}\) between this study and Gautier (GOES, from 03/97 to 04/94, excellent agreement with Li (ERBE, from 11/1984 to 12/1989).
Section 3: Uncertainties of SW and LW flux and CRF due to the background difference between clear sky and cloudy
Surface albedo

and upwelling LW flux differences between clear-sky and cloudy periods

The current SW CRFs would be -2.7 Wm\(^{-2}\) lower, and LW CRFs -5.5 Wm\(^{-2}\) lower if we used cloudy surface albedo and upwelling LW flux.
Different atmospheric water vapor amounts due to different SW and LW fluxes.
New parameterizations of downwelling SW and LW flux to water vapor amounts from 6 years of clear-sky dataset.
Comparing to measured clear-sky fluxes, the corrected downwelling SW flux is about 33 Wm$^{-2}$ less, and LW flux is about 33 Wm$^{-2}$ more. They cancel out.
Conclusions

1) Cloud fraction: a) the total and low clouds occur greatest during winter and spring, and least often during summer; (b) the high clouds occur most in all four seasons than other types of clouds with a peak in summer; (c) the middle clouds occur least than others; and (d) the multilayer clouds are common.

2) According to their CRFs, clouds can be classified into 2 groups: the group 1 includes total and low clouds- strong SW cooling effect, large LW warming effect, and strong net cooling effect on surface; the group 2 includes all-sky, middle and high clouds- weak SW cooling, small LW warming, and weak net cooling effect on surface.

3) The NET CRFs would be slightly less (~8 Wm$^{-2}$) if the cloudy surface albedo and upwelling LW flux were used in the calculation of CRF. The annual NET CRFs should not be affected significantly by different clear-sky and cloudy backgrounds although the SW and LW CRFs may be more or less affected at individual month.
Thanks for your attention!
Diurnal cycle of clear-sky flux and CRF at the ARM SGP site

Winter

- LW = -85
- SW = 124
- NET = 39

Summer

- LW = -74
- SW = 260
- NET = 186

Legend:
- All sky
- Total cloud
- Low cloud
- Middle cloud
- High cloud

Y-axis:
- Flux clear (Wm^-2)
- LW CRF
- SW CRF
- NET CRF

X-axis:
- Local hour (0 to 24)

Graphs (a) to (h) show the diurnal variation of clear-sky flux and CRF for different cloud categories during winter and summer.
Diurnal cycle of downwelling SW and LW fluxes at the ARM SGP site

Annual

Winter

Summer

Local hour
Vertical distributions of clouds at the ARM SGP site